The TREND IN ENGINEERING

at the University of Washington

In this issue:

NEW TRENDS IN CERAMICS

WASHINGTON COAL GASIFICATION STUDIES

FLAT-EARTH TRANSFORMATION AND ITS MATHEMATICAL INTERPRETATION FROM SPHERICAL GEOMETRY

INSTRUMENTATION IN INDUSTRIAL HYGIENE AND AIR POLLUTION

October, 1954

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THE ENGINEERING EXPERIMENT STATION

As a departure from its regular policy, *The Trend* invites reader comment on the need for a critical review of engineering education, and will publish such material, subject to space restrictions.

A PROTEAN HAUL
from the *Journal of Engineering Education*

"Only the gamefish swims upstream,
The sensible fish swims down."

A RE-VIEW OF RECENT NUMBERS of the ASEE **Journal** reveals the vigorous attention which engineering educators and industrial keymen are directing toward curricular problems. Some of the most engaging discussions continue to revolve around the humanistic-social program. The grant, about a year ago, of $30,000 from the Carnegie Corporation "to make a comprehensive analysis of curricular programs in those colleges which have given considerable thought to the humanistic-social stem," is a tangible recognition of its importance. Perhaps as significant, is the degree to which references to "liberal education" have spilled over into articles of most disparate titles.

With few exceptions, the humanities seem to be accepted as a necessary part of educating "the whole man." But how to develop this stem of the curriculum, without weakening the technical structure, is the problem. A complicating factor is the pressure, often justified, for new courses to cover recent technological developments. As one writer puts it, "the jug is full," though he goes on to suggest means of reducing some of its present contents.[1]

The Preliminary Report of the Committee on Evaluation[2] cleared up any doubt as to what is covered in the term, "humanistic-social."

> The seeking for immediate usefulness in the social studies and humanities, as tool subjects in engineering, may well lead to failure to achieve the objectives set forth above. Such courses as accounting, industrial psychology, investment economics comparative costs, or city management may be just as technical as engineering studies. It is outside of such fields that the social-humanistic studies must lead the student. The Committee recommends a much broader study of the effectiveness of the social-humanistic stem of engineering education.

This may prevent such curricular grouping as appears in one report:[3]

Humanistic-Social Sciences, etc. (15%)
Physical Education (and Mil. Science where required)
Economics, General and Adv. or Amer. Hist. or Pol. Science.
English, Rhetoric and Compos. and Literature, or Tech. Writing, or Public Speaking, etc.

With an easily understood reluctance to avoid, if possible, extension of the four-year course to five, several writers suggest general approaches to the problem of the full jug.

1. To trim and compact the present technical curriculum

> In order to make room for such training [in the humanities], some subjects must be combined or reduced in scope, such as water supply, sewage and highways, heating, air conditioning, refrigeration, advanced communication circuits and industrial electronics. Some of this type background can be covered during summer employment or field trips, and in general such subjects can be more readily acquired later when needed than can the more basic engineering subjects.[4]

> In our college curricula perhaps we should consider a closer integration of the introductory engineering subjects to obtain a more efficient use of the early years, thus effectively lengthening the period for higher level training. . . . For what the student is taught at the start is the basic platform upon which all else must stand. . . . From this standpoint, perhaps we have been giving far too little attention to the introductory portions of engineering education and concentrating too much on how we can get adequate coverage in the more specialized fields of engineering.[5]

2. To combine the senior high-school year with a 4-year university course

> Two of the various suggestions adaptable to our special requirements . . . present a combination of an extended four year engineering curriculum and of an honor program. Some of these plans . . . are at present under serious consideration by appropriate committees at the College of Engineering of Rutgers University.

(Continued on page 29)

THE ENGINEERING EXPERIMENT STATION of the University of Washington was established in December, 1917, to coordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is three-fold:

(1) to investigate and publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural, and industrial affairs;

(2) to undertake extended research and to publish reports on engineering and scientific problems;

(3) to provide opportunities for graduate engineers to conduct research under conditions that will most effectively prepare them for professional service.

For administrative purposes the work of the Station is organized into nine divisions:

1. Aeronautical Engineering
2. Chemical Engineering, Industrial Chemistry
3. Civil Engineering
4. Electrical Engineering
5. Forest Products
6. Geology
7. Mechanical Engineering
8. Mining, Metallurgical, Ceramic Engineering
9. Physics Standards and Tests

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New Trends in Ceramics

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E. E. Mueller

From its inception at Glass House Point, Virginia, in 1608, the first industrial plant in the United States, the ceramic industry has grown steadily until it now has a product value of about $5 billion yearly. That it has grown not only in size, but in comparative importance to all other branches of industry is evidenced in the statement by Henry Ford, II: "To say that ceramics are indispensable to the automotive industry and industry in general might well be termed an understatement." Maurice Nelles, Director of the Borg-Warner Control Research Laboratory, feels that "ceramics will constitute the next most important age in the world."

Applications of ceramic products are wide and diverse. Not only are they used as components in many products, but in some stages of production of almost any manufactured article that comes to mind. Many of these developments have occurred in only the last few years.

Generally speaking, the following properties or characteristics can be obtained with ceramic products: widespread availability; inherent cheapness; ease of fabrication; chemical resistance, including resistance to oxidation (fireproofness); high-temperature resistance; high strength, especially in compression; phenomenal optical properties, including transparency; hardness; and desirable electrical characteristics.

A review of some of the more recent developments, for use in various engineering fields, follows. In a case such as ceramic coatings and fiber glass, where the product or development is, of course, difficult to restrict to one field, the description is usually given of the most important application.

Aeronautical Engineering

Recent developments in ceramic coatings are finding widespread usage in the aircraft industries. They are generally considered for one of three purposes: (1) to allow substitution for less strategic alloys without sacrificing service life; (2) to lengthen the service life of existing parts; and (3) to allow use of existing parts at higher operating temperatures.[1] During World War II, the largest application was for turbo-superchargers, and before that, for automobile mufflers. They are in limited use at present except for exhaust stacks and combustion chambers, but many manufacturers have coated parts under development and are testing for other applications.

J. I. Mueller

Another use of ceramic coatings is for the protection of aircraft skins from the high temperatures generated by air friction. Successful vitreous enamels have been developed for aluminum and titanium, and work is progressing on enamels for magnesium. Some work has been done in the Ceramic Engineering Division at the University of Washington on aluminum and titanium enamels and several national awards have been granted to the research workers.

Some of the high-temperature refractory coatings successfully employed during the past few years are only 0.001 in. thick, and new techniques of flame spraying make possible a coating which can be welded through. Nickel-magnesium ceramic combinations have been successfully applied to stainless steel, Inconel, and other high-temperature alloys, and will withstand temperatures up to 3500° F for limited periods.[2]

Glass fibers have found many uses in the aircraft industry, both alone and in combination with other materials. Much of the electrical wiring uses fiber glass for electrical insulation. Fiber matting is used for thermal insulation. Reinforced by various resins and plastics, glass fibers have many other applications. One of the more recent uses is for radomes. Many housings of various types replace aluminum and other materials. Air ducts, junction boxes, and most of the safety equipment on the B-47 are made from this combination.[3]

LEGEND *(Clockwise from upper left):* **(1) Glazing 138-kv condenser bushing casing. (2) Electrical flashover test on 10-in. suspension insulator.** *(Both photographs courtesy of* WESTINGHOUSE ELECTRICAL CORPORATION, *1954)* **(3) Raising 47-ft prestressed ceramic tile beam at Clay City, Washington.** *(Courtesy* BUILDERS BRICK COMPANY.) **(4) Ferromagnetic ceramics as used in television and other electronic equipment.** *(Courtesy* GENERAL CERAMICS AND STEATITE CORPORATION, *Keasbey, N.J.)* **(5) Chemical and industrial porcelain and alumina dielectrics.** *(Courtesy* COORS PORCELAIN COMPANY.)

Chemical Engineering

Because of their inherent resistance to most types of chemical attack, ceramic products are used widely in most chemical industries. Recent developments of phosphate glasses have even made possible resistance to hydrofluoric acid, the most notorious attacking agent of the siliceous ceramics.

In the petroleum industry, a widespread usage of ceramic products is made. Typical examples would be H_2SO_4 tar tanks, sludge kettles, chemical plant reactors, SO_2 drier towers, etc. Glass is used in many forms: by itself, in large pieces of pilot-plant equipment; as a lining, over steel and cast iron, for tanks, reactors, and pipes; and as fibers, in insulation, fabrics, tower packing, and plastic laminates.

For spray nozzles, handling corrosive acids at 150° F inside and hot gases at 650° F outside, bonded silicon carbide is now being used in place of cast 8 per cent antimonal lead. The older material in some cases lasted only three months and cost 25 per cent more than the SiC which is still in service after fifteen months.[4]

A new magnesia refractory, nearly 97 per cent pure, has many applications in the chemical and metallurgical industries. Its present uses are for the processing of molten salts and lime and in the manufacture of calcium chloride. It is also used in the lead industry for smelting and purifying operations.[5]

New developments in vitreous silica allow it to be used as an acid burner for the manufacture of synthetic hydrochloric acid and in acid cooler manifold sections in the manufacture of other chemically pure acids.[6] Other uses are for calcining and evaporating trays, furnace muffles, and evacuation chambers in induction furnaces.

Civil Engineering

From the beginning, one of the major uses for ceramic products has been in construction. Many new methods and materials are now available for structural use.

Among these is reinforced brick masonry, which is becoming very popular in earthquake zones and areas where horizontal thrusts from atomic explosions may be imminent. Prestressing of building components in the form of beams and roof slabs has recently been shown in the construction of a building at Clay City, Washington. (See illustration of prestressed ceramic beam on page 4.)

Light-weight aggregates from expanded clays and shales have recently become almost commonplace. In the construction of the Chesapeake Bay Bridge, recently completed, a saving of 12,000,000 lb was made by using expanded shale as aggregate in the 3¼-mile deck. More recently, light-weight aggregate was used on the new roof of the Capitol building in Washington, D.C.[7]

A section of the Marine Corps Air Field at Wilmington, N. C., is presently the scene of a series of tests where semirefractory paving blocks are being used in a warm-up apron for jet planes. Some of the tests to be given this clay block strip will be more severe than have ever been given to any other type of pavement. For example, a dead load of 50,000 lb will be concentrated on a very small area to simulate the downward thrust of a heavy plane landing. Also, it will be subjected to the hot gases of jet engines. What temperatures will actually be attained is not known, but probably in the range of 1500° to 2000° F, at the distance from the engine to the pavement. If the tests are successful, the Postonway road would eradicate the damage problem caused by jet and rocket exhausts on conventional concrete.[8]

A new curtain wall construction is now available which utilizes cellular glass sandwiched between porcelain enameled sheets. Walls approximately two inches thick weigh only seven pounds per square foot. Advantages of this type of construction are the light weight, good insulating properties, low maintenance costs, incombustibility, and dimensional stability.[9]

Electrical Engineering

Rapid advances in electrical ceramics have been made since the end of World War II. Among the more recent ones, various forms of synthetic mica have been made and bonded with glass and are currently being produced in quantity. Their useful properties include lower loss factors at high frequencies than most insulating materials, dielectric strength in or above the range of the best insulators, high arc resistance, and high tensile and compressive strengths. Operating temperature ranges up to 650-700° F.[10]

Ceramic magnets made of $BaCo_3$ and FeO_3 are being used for TV focusing. These can be formed in several shapes by various processes and are valuable for their high permanent magnetic quality.[11]

A new type of sintered alumina is available which is virtually free of any glassy bond. Properties of this sintered material approach those of a single crystalline material of sapphire type. They are presently being used as tube envelopes which operate at 10,000 mc. They offer good mechanical strength, a surface which takes readily to metallizing, and low dielectric losses, even after heating in a reducing atmosphere.[12,13]

Glass reinforced plastics are available for use in electric motors and generators as slot sticks, spacers, armature end laminations, coil head insulation, etc. They also can be used for electrical shim stock, electromagnet intercoil spacers, control finger panels, transformer spacers, and terminal locks.[3]

New lithium-containing ceramics with excellent dimensional stability and thermal shock resistance

CERAMIC-COATED AIRCRAFT EXHAUST SYSTEM
(Photograph courtesy RYAN AERONAUTICAL COMPANY, *Los Angeles)*

are available. In laboratory treatment they have been heated to 2000° F and plunged into liquid air (-310° F) for 10 cycles without any apparent ill effects.[14]

Printed circuits on a ceramic base now can be combined in extremely compact units making a complete resistor and capacitor electric circuit with external leads for connecting into electric or electronic assemblies.[15]

"Project Tinkertoy," sponsored by the Navy Bureau of Aeronautics and developed at the National Bureau of Standards, has developed a method of producing complete electronic units automatically. Cost experts expect this method to cut production costs approximately 40 per cent. Standard "building blocks" are assembled into modules which will replace the complicated mass of wiring at present characteristic of conventional electronic equipment. The wafers making up these units are made of various ceramic materials, the selection of which depends upon the ultimate use.

Ferrite materials offer many other possibilities for magnetic cores and applications in carrier frequency power transformers, pulse transformers and harmonic generators, magnetic amplifiers, filter and loading coils, magneto-strictive oscillators, and concentrators for high-frequency heating.[16]

Mechanical Engineering

New materials for bearings are being produced for specialized applications. Among these is a synthetic sapphire which can be used for light loads. Sphericity tolerances of 0.00002 in. can be held on balls of ⅜-in. diameter, or less. Sapphire is also used in tapered flow meters and rhotometers for handling liquid chlorine. It is becoming very widely used in the textile industry for thread guides since it greatly outlasts metal and porcelain. This same hardness enables it to be used as bearings for watches, instruments, and meters of various types. Its insulating properties also permit its use for spacers in electronic equipment.[17]

Glass coating on steel and cast iron is now used extensively to provide a corrosion-resistant finish and deter clogging for boiler and other fluid transfer applications. Many domestic hot-water heaters are

(Continued on page 26)

FIG. 1. MAP OF WESTERN WASHINGTON SHOWING LOCATION OF COAL DEPOSITS

WASHINGTON COAL GASIFICATION STUDIES

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The many problems concerning the economic utilization of low-grade carbonaceous fuels have tended to discourage the development of large subbituminous coal deposits in this state. Washington has, primarily in the western parts, estimated reserves amounting to 23,000,000 tons of anthracite, 11,000,000 tons of bituminous, and 52,000,000,000 tons of subbituminous coals. These amount to 0.1, 0.80, and 5.26 per cent, respectively, of total United States reserves. Approximate locations of these deposits are shown in Fig. 1. This vast potential energy source prompted the study of methods of coal utilization.

Methods of Coal Utilization

The most important methods of coal utilization are combustion, extraction, carbonization, hydrogenation, and gasification.

Combustion is the simple conversion of the coal to heat, which in turn may be used for many domestic and industrial applications. Extraction involves the use of a suitable solvent at favorable temperatures and pressure to dissolve out usable organic materials.[1] The remaining coal may be coked and utilized as high-grade electrode carbon. Carbonization is the process of subjecting coal to destructive distillation in the absence of oxygen. The primary products are char, tar, oils, aqueous liquor, and gas. The process may be carried out at either high or low temperature. The low-temperature system is characterized by high yields of primary products except for gas, whereas the high-temperature approach produces less of the liquids and more secondary gaseous products.[2,3,4,5] Hydrogenation consists of reacting hydrogen with the complex coal molecules and replacing oxygen and nitrogen so that the chemical constitution is changed toward that of petroleum, thus producing a liquid product.[6,7,8] Gasification is the reaction of steam and oxygen with carbon in the coal to produce a gaseous mixture containing carbon monoxide, hydrogen, and carbon dioxide. It is desirable to have a hydrogen-to-carbon monoxide ratio in the mixture of about one to one. At this ratio the mixture is suitable for synthesis gas and may be sold as such.

Previous Work

R. W. Moulton

Early work with these various methods at the University of Washington indicated that extraction and carbonization both give poor yields, thus limiting the economics of the process.[9,10,11] On the other hand, laboratory experiments with hydrogenation of Washington coal showed the possibility of 90 to 95 per cent liquifaction. While the yields are good, the nature of the process still makes it expensive.[12] Since gasification appears to be better from an economic standpoint than any of the aforementioned processes, work was diverted to investigating this method of utilization.

Early investigators, working with the gasification process, found that it would be necessary to eliminate excessive heat losses from the equipment before satisfactory yields of synthesis gas could be obtained.

With this knowledge, and favorable results by the Winkler fluidized-bed process, Istas and Runciman designed a three-unit fluidized-bed pilot plant, with coking, burning, and gasifying beds. This design not only capitalizes on recovery of coking products, but also allows control of the gasification process in each unit. The results of these preliminary investigations are analyzed in the Ph.D. thesis by Dvoracek.[13]

Theory of Gasification

The process involves three main principles: coking, combustion, and gasification.

In carbonization, or coking, some of the process variables, such as physical properties of the coal, type of reactor bed, temperature, and retention time, play important roles. Washington subbituminous coals have non-coking properties and are unsuitable for the manufacture of coke. Since a fluidized bed is to be used, swelling of the coke particle will affect the retention time. Singh's work[14] indicates that retention times are small and thus are important factors in the design of the coking section in a fluidized system.

The two remaining principles, combustion and gasification, may be separated into exothermic reactions, reactions of carbon with oxygen; and endothermic reactions, reactions of carbon with steam.

In the combustion or burning section, heat is liberated by the following reactions:

$$C+1/2\,O_2 \longrightarrow CO$$

$$C+O_2 \longrightarrow CO_2$$

These reactions are kinetically quite fast and are not believed to control the over-all process.

In the gasification section, the following main endothermic reactions take place:

$$C+H_2O=CO+H_2$$

$$C+2H_2O=CO_2+2H_2$$

It is now believed that these reactions may be kinetically quite slow, and thus controlling. There are many side reactions of little or no effect at atmospheric pressure. However, should operating pressures be raised to 20 atmospheres, carbon will react with hydrogen to give methane. If a fuel gas is desired, this reaction will automatically carburet the gas from 250 Btu per cubic foot to 450 Btu per cubic foot.

As may be noted from the above discussion, heat will be at a premium in this operation. The most common method of gasification is to have all the reactions taking place in one unit. This, as already mentioned, allows very little control over the reactions. Another convenient method is by use of externally heated retorts. A third, and newest of the three methods, would be the circulation of hot coke from one reaction zone to another, thus accomplishing heat transfer.

Methods of Gasification

The use of a fluidized bed is becoming more common today. The most important gasification process is the Winkler design which was first designed and operated in Germany in 1942. Since then, several units have been built in this country. The problem of ash removal is always involved. In the case of the Winkler unit, fly dust accounts for 90 per cent of the ash, while the remainder is removed at the bottom of the unit.[9,15,16,17]

The fixed-bed type of system is also widely used. A typical fixed-bed operation is the Lurgi system, where, under a pressure of 20 atmospheres, the fixed coal bed is subjected to a mixture of oxygen and steam. Ash is removed at the bottom by a grate system.

Suspensions of powdered coal in oxygen and steam streams, injected into a reacting zone, also have been studied. The main problem in this case involves slagging.[18,19,20,21]

Other means such as slagging generators, where the temperature of operation is high enough to allow the ash to be removed in the molten state,[20,22] externally heated retorts, especially good for lignites and high volatile subbituminous coals, [23,24] as well as underground gasification, may be utilized.

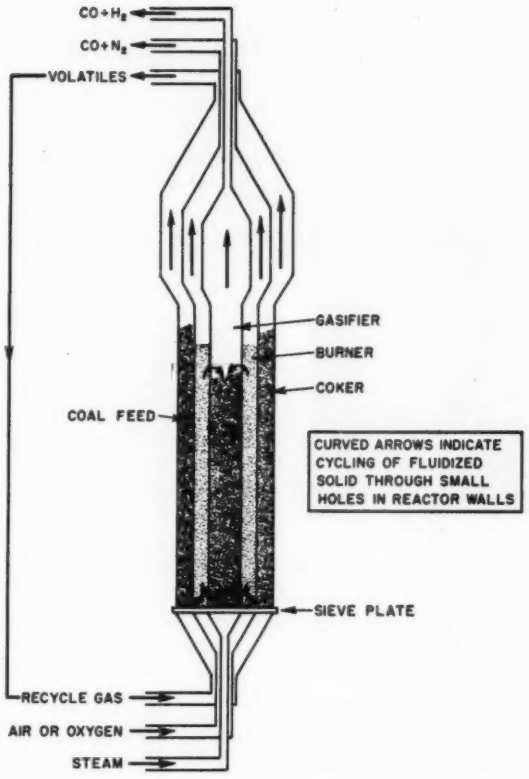

FIG. 2. PILOT-PLANT REACTORS

Pilot-Plant Design Features

The coal gasification pilot plant, built under the direction of the Chemical Engineering Department, utilizes a hot coke heat-transfer system. The main part of the pilot plant consists of three concentric reactors constructed of type 302 stainless steel. Figure 2 shows the main section of the pilot plant. As shown, the outside unit is the coker, next is the burner, and the center unit is the gasifier. The section diameters are 15, 10, and 5 inches, respectively. The height from the expansion chamber to the sieve plate is 48 inches. Since the pressure drop in a fluidized bed is governed by the amount of material in it, and not by the velocity of the gas, coal will then be transferred at the bottom of the coker through holes into the burner, thence from the top of the burner into the gasifier and back into the burner at the bottom of the gasifier. Although some heat is transferred through the burner wall, the recirculating action of the hot

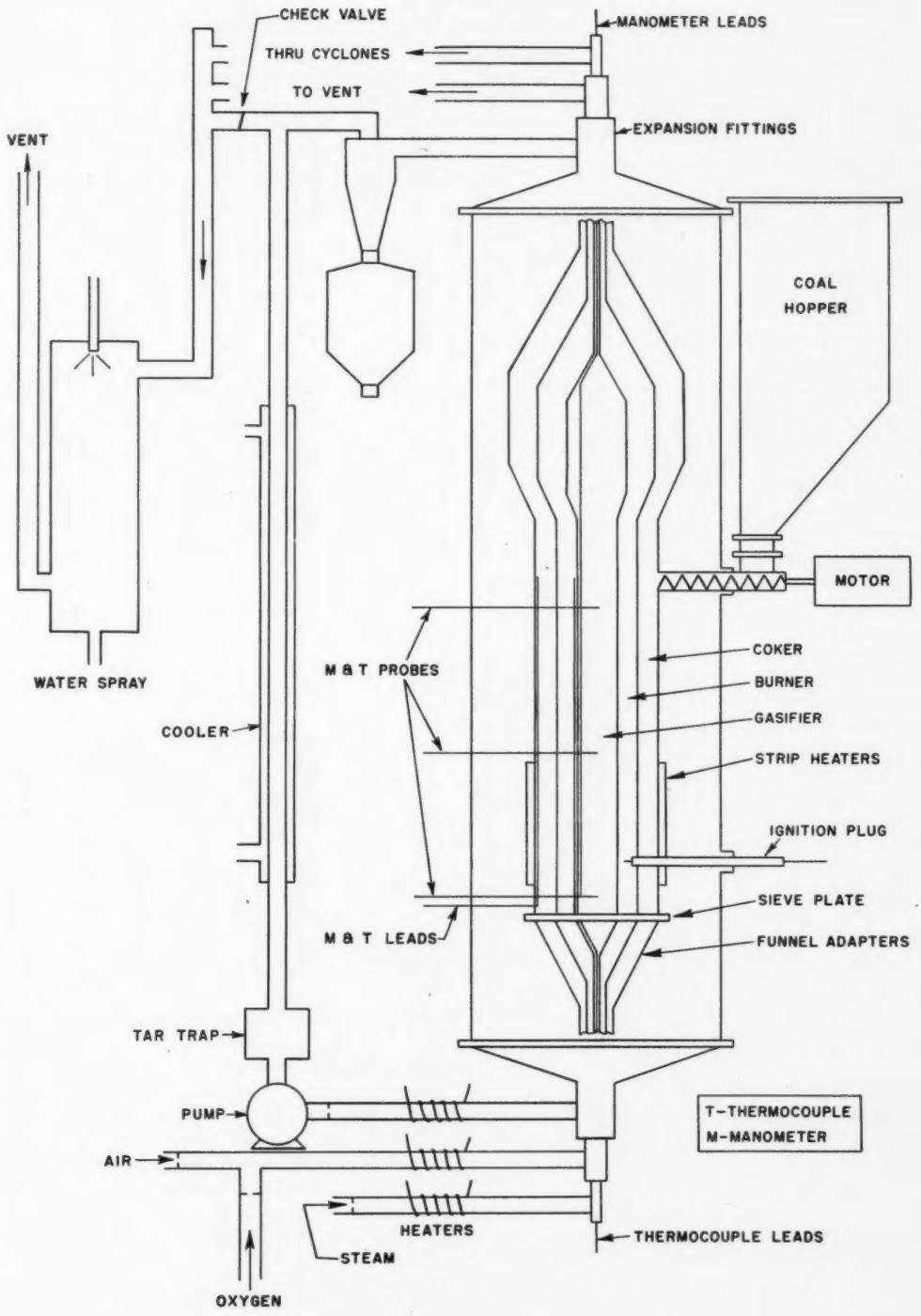

FIG. 3. DIAGRAM OF COMPLETE PILOT PLANT

TABLE I

DATA AND ANALYSES FROM PILOT-PLANT OPERATION

RUN NO.	A	B	C	D	E	K	L	M	N	O	P	Q	S	T	U
Coal															
Proximate Analysis (%)															
Water	11.2	11.2	12.3	12.3		16.0	16.0	16.0	16.0	16.3	16.3	16.3	14.7	14.7	14.7
Volatile Matter	33.1	33.1	36.9	36.9		39.3	39.3	39.3	39.3	36.9	36.9	36.9	37.8	37.8	37.8
Fixed Carbon	45.3	45.3	39.6	39.6		36.7	36.7	36.7	36.7	39.8	39.8	39.8	40.0	40.0	40.0
Ash	10.4	10.4	11.2	11.2		8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.5	7.5	7.5
Size Analysis (%)															
28 mesh						7.1	7.1	7.1	7.1	15.1	15.1	15.1	17.6	17.6	17.6
28-35 mesh	11.8	11.8	0.8	0.8		31.1	31.1	31.1	31.1	39.3	39.3	39.3	49.7	49.7	49.7
35-48 mesh	22.8	22.8	10.5	10.5		27.9	27.9	27.9	27.9	26.8	26.8	26.8	16.6	16.6	16.6
48-65 mesh	27.3	27.3	28.2	28.2		23.1	23.1	23.1	23.1	16.0	16.0	16.0	9.8	9.8	9.8
65-100 mesh	11.8	11.8	20.2	20.2		8.7	8.7	8.7	8.7	0.9	0.9	0.9	4.1	4.1	4.1
100-150 mesh	18.2	18.2	32.2	32.2		0.8	0.8	0.8	0.8	1.8	1.8	1.8	2.1	2.1	2.1
150-200 mesh	4.5	4.5	4.8	4.8		0.4	0.4	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
200 mesh	3.6	3.6	3.2	3.2		0.8	0.8	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Temperatures (°F)*															
Coker															
1	1150	1245	970	1406						1035	1205	1055	750	865	1115
2	1142	1192	1000	1295		720	1030	790	980	955	1035	855	1430	1390	1500
3	1366	1395	1295	1490				660							
4	1277	1316	1312	1215											
Burner										1445					
1	1214	1278	1100	960							1405	1370	970	885	1025
2	1355	1405	1329	1552		994	1117	1200	1320		1095	1100	1400	1400	1605
3	1425	1415	1472	1568		1310	1034	970							
4	1425	1436	1524	1680											
Gasifier															
1	1243	1308	1146	1460											
2	1330	1373	1330	1472									810	925	1105
3	1350	1386	1395	1490		940	910	1000	1070	910	990	1055	1400	1350	1450
4	1362	1386	1406	1472		990									
Recycle	500	460	275	422											
Air and/or Oxygen	70	70	80	80		476	375	305	195	320	350	170	610	195	200
Steam	220	220	220	220		85	80	80	100	70	70	70	630	640	610
Coker Exit	270	220	230	440		220	220	220	220	220	220	220	650	560	565
Burner Exit	500	570	410	640		472	610	625	685	640	665	610	465	600	555
Gasifier Exit	230	270	253	390		655	900	795	840	735	790	790	520	685	680
Gas Composition (Vol %)						175	165	145	155	230	210	150	300	420	410
Coker															
CO_2	5.9	11.4	15.8	10.5	12.6	13.3	12.8	15.5	18.9	11.9	16.8	16.2	10.8	14.2	8.5
CO	4.6	11.4	13.0	12.5	4.7	17.8	13.7	7.8	3.8	11.4	7.8	4.1	14.3	9.8	21.4
O_2	3.3	0.0	0.0	0.0	1.0	0.4	0.4	0.0	0.4	0.8	0.4	1.1	0.9	0.4	0.9
Unsaturates	0.0	1.6	1.9	2.0	1.0	0.4	0.4	1.2	1.5	1.7	2.5	3.0	1.3	0.8	0.0
H_2	1.7	0.0	1.4	0.0	6.7	9.5	17.4	7.6	8.5	1.0	15.4	9.1	21.7	17.8	25.5
CH_4	1.3	1.8	0.0	0.0	3.3	4.3	4.4	1.0	5.1	3.0	6.8	6.2	8.9	13.4	5.5
N_2	48.8	55.0	60.8	40.9	23.3	43.2	36.2	48.5	37.2	54.8	32.0	34.1	28.5	22.4	23.6
H_2O	34.2	18.8	7.1	34.0	47.4	11.0	14.7	18.3	24.6	15.4	18.3	26.3	13.6	21.2	14.6
H_2/CO Ratio	0.40	0.00	0.10	0.00	1.40	0.54	1.28	0.96	2.24	0.09	1.98	2.24	1.52	1.80	1.19
Burner															
CO_2	9.5	10.6	11.3	9.8	21.9	12.8	11.4	12.5	18.6	17.1	19.5	17.5	10.3	13.8	10.1
CO	7.3	8.2	6.6	39.2	10.5	15.1	14.1	10.7	1.8	9.9	9.7	5.7	15.9	7.9	21.2
O_2	0.0	0.8	1.9	0.5	0.9	0.3	0.4	0.8	0.4	0.4	0.0	0.3	0.0	0.4	0.9
Unsaturates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H_2	0.0	1.7	1.7	0.0	5.5	2.0	10.5	9.6	2.6	8.4	8.7	7.3	11.8	15.2	15.7
CH_4	1.4	0.0	0.0	0.8	2.1	0.0	2.6	3.9	2.6	6.3	5.2	2.2	6.0	8.5	5.3
N_2	54.6	60.8	73.0	47.7	54.3	58.4	39.4	38.7	46.8	47.7	38.1	34.3	41.8	33.2	31.4
H_2O	27.2	18.2	5.5	2.1	4.7	11.4	21.5	23.9	27.2	10.2	18.7	32.5	14.1	21.1	15.3
H_2/CO Ratio	0.00	0.17	0.25	0.00	0.52	0.13	0.75	0.90	1.44	0.85	0.90	1.27	0.74	1.92	0.74
Gasifier															
CO_2	6.2	25.0	9.6	9.2	0.7	16.7	18.1	19.9	19.1	20.6	19.3	14.0	8.0	15.3	14.2
CO	1.8	8.0	3.0	13.1	0.0	11.2	1.5	0.4	0.8	7.0	13.2	12.1	6.7	5.1	9.1
O_2	0.0	1.0	0.0	0.0	28.6	0.3	0.4	0.2	0.8	1.3	0.4	0.4	0.7	0.0	0.0
Unsaturates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H_2	6.5	22.0	12.7	10.8	0.0	17.8	17.0	19.6	16.8	15.6	14.8	12.0	14.9	19.2	26.5
CH_4	0.0	1.1	0.7	1.1	0.0	1.4	2.7	1.4	1.4	2.9	2.5	2.6	3.2	7.8	5.0
N_2	11.4	42.9	24.6	22.8	44.0	37.1	34.4	35.0	37.7	40.0	32.1	36.8	13.8	25.3	18.2
H_2O	74.0		49.4	42.9	26.6	15.5	25.8	23.6	23.4	12.6	17.7	22.0	52.7	27.3	27.0
H_2/CO Ratio	3.60	2.80	4.20	0.80	0.00	1.60	11.40	51.30	21.90	2.24	1.12	0.99	2.22	3.76	2.91
Coal Feed Rate (# /hr)†	17.0	17.0	14.4	14.4		15.0	15.0	15.0	15.0	25.0	25.0	25.0	18.6	18.6	18.6
Flow (cu ft/min, 60°F, 30" Hg)															
Recycle			1.1	1.7		5.2	6.5	6.8	7.6	8.0	9.7	6.5	7.2	11.6	
Air and/or Oxygen			9.2	7.3		9.4	9.9	8.5	7.9	8.8	8.3	7.1	7.3	7.9	4.2
Steam			2.9	3.6		3.4	6.4	6.0	5.2	2.4	4.4	4.6	3.7	5.0	9.0
Coker Exit			1.8	2.5		3.8	4.9	4.5	5.3	4.6	6.8	6.1	6.9	11.3	5.3
Burner Exit			8.4	8.7		14.0	17.0	17.6	15.8	12.6	13.7	14.0	9.0	13.1	9.5
Gasifier Exit			1.8	3.6		1.5	2.1	2.1	1.7	2.6	2.1	1.6	1.5	4.2	11.4
H_2 Produced			0.4	0.4		3.1	2.2	2.1	0.7	1.5	1.5	1.3	1.3	2.7	4.4
CO Produced			0.7	4.0		2.3	2.4	1.9	0.3	1.5	1.6	1.0	1.5	1.3	4.3
H_2/CO Ratio			0.56	0.10		1.35	0.92	1.10	2.30	1.00	0.94	1.30	0.86	2.10	4.0
N_2 Entering			7.9	4.3		9.1	9.4	9.4	8.2	10.5	7.5	6.7	7.5	8.5	1.10
N_2 Leaving			7.6	6.0		10.4	9.2	9.7	10.0	9.6	8.1	7.5	6.0	8.0	7.2
O_2 Entering			4.6	6.8		6.9	9.1	8.7	8.8	7.5	9.8	8.3	6.8	9.3	6.6
O_2 Leaving			2.7	4.6		5.2	7.1	7.3	7.6	6.0	7.5	7.7	4.7	8.5	8.6
Ash (Burner Cyclone)															6.9
Proximate Analysis															
Water	2.1	2.1	2.5	2.5		1.1	0.4	1.5	1.0	0.0	0.0	0.3	4.7	5.0	
Volatile Matter	7.8	7.8	9.7	9.7		7.3	6.6	6.2	5.0	5.1	7.2	7.4	13.8	19.3	4.8
Fixed Carbon	59.1	59.1	46.3	46.3		66.1	59.2	53.6	62.3	76.3	74.7	62.7	54.4	46.7	11.9
Ash	31.0	31.0	41.5	41.5		25.5	33.8	38.7	31.7	18.6	18.1	29.6	27.0	29.0	48.7
Size Analysis (%)															34.6
28 mesh	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0			
28-35 mesh	0.0	0.0	0.6	0.6		1.0	0.0	0.0	0.0	3.3	4.4	6.1			0.0
35-48 mesh	0.0	0.0	0.6	0.6		6.0	0.9	2.0	0.7	9.8	10.5	10.8			0.0
48-65 mesh	0.0	0.0	1.7	1.7		10.0	17.4	10.0	4.6	13.1	14.9	9.2			0.5
65-100 mesh	4.8	4.8	4.6	4.6		19.0	49.6	14.0	16.8	4.9	1.7	0.0			8.6
100-150 mesh	43.6	43.6	35.6	35.6		37.0	16.4	52.0	29.0	51.6	47.4	38.5			42.1
150-200 mesh	29.0	29.0	32.0	32.0		9.0	3.6	6.0	15.3	9.0	5.3	4.6			36.4
200 mesh	22.6	22.6	24.1	24.1		18.0	11.9	16.0	33.6	8.2	14.9	15.4			6.7
															5.7

*†See opposite page for footnotes.

carbon particles supplies most of it. Figure 3 shows the complete installation. Figure 4 is a photograph of the pilot plant.

The three concentric reactors are surrounded by a pressure shell and insulating section. This type of construction is to allow for future operation at elevated pressure up to 150 psig. Nitrogen or some other inert gas must be used as a pressure compensator to prevent the thin-walled unit from failing at high temperature and pressure operation.

The coal-feed hopper is constructed of steel and is also pressurized with nitrogen to prevent blowback through the feed screw. The feed rate is controlled by means of a variable speed motor.

Since it is quite necessary to keep reactive gases from the coker section, it was decided to recycle the coker gas as the fluidizing medium for the coker bed. This required cooling the gas for pumping and then preheating it before it re-enters the coker. The burner and gasifier beds are fluidized by air and/or oxygen, and steam, respectively.

Transversing chromel-alumel thermocouples are used to record temperatures at different points in the reactor bed. Pressure drop at various points across the reactor determines the height of the fluidized beds.

Analysis of gas streams is accomplished by means of standard orsat equipment.

Coal Preparation

Coal used in the pilot plant was secured from Mr. W. Strain, Centralia, Washington. Since only a fraction from 20 to 100 mesh was used, it was necessary to process a considerable amount of coal. The coal was first ground in a hammer mill and then classified through a special screener.

Operating Procedure

It was necessary to preheat the reactors to 1000° F in order to ignite the coal particles. This was accomplished by introducing air and city gas into the burner and igniting the mixture. When the temperature of the burner exceeded 1000° F, the steam and recycle streams were introduced, and the coal feed turned on. If the temperature continued to rise, the gas was shut off.

The pilot plant was now on stream, and flow conditions were adjusted to obtain the desired temperature. The temperature was controlled by the amount of oxygen admitted into the burner section. The apparatus was allowed to come to equilibrium, and a complete set of data was taken. This included all gas stream analyses, temperatures, and flow rates. At least two sets of data were taken with each 8-hour run.

Shutdown was accomplished by introducing nitrogen in the burner and turning off the air. This was continued until it was quite certain that the reactor beds were below the clinkering point.

The raw data were analyzed and are presented in Table I, which lists the results of 15 runs.

Discussion of Individual Runs

Runs A and B showed a high hydrogen-to-carbon monoxide ratio; also ash was collected in the cyclones, which was encouraging. However, runs A and B were intended mostly for familiarization with the equipment. Runs C and D provided the first complete set of data. Low production of hydrogen was noted, along with a small ratio of hydrogen to carbon monoxide. At this point temperature control was quite difficult. Runs E through I showed no hydrogen production. This indicated no coal in the gasification section. Since changes in back pressures and flow rates did not alter the situation, a model was constructed, in order to study the bed fluidization.

As a result of the model studies, it was found necessary to enlarge the coal-transfer holes in the burner-coke wall from ¼ inch to ½ inch. When the pilot plant was dismantled to correct the transfer hole size, a surprising development was noted. The lower 12 inches of the burner section was solid with clinkers. The 302 stainless steel wall was melted and had holes burned in it, thus indicating temperatures of at least 2600° F. A check on the thermocouples indicated that they may have been defective. At this point traversing thermocouples were installed, and the reactor was rebuilt. Runs K through N indicated good operation with excellent temperature control. It was noted, however, that the nitrogen content of the coker gas was high, indicating a leak from the burner into the coker. After correcting back pressures, runs O through Q were made. The results here still indicated a high nitrogen content, but this was explained by a plugged recycle line. After cleaning, run R was started, but no hydrogen was present in the gasifier stream. This indicated that the reactor was clinkered. It may be noted that the hottest point, as measured by the corrected thermocouples, never reached 2100° F, the fusion point of the ash. Disassembly of the unit showed that clinkering had taken place. Heat balances on runs K through N showed a 31 per cent heat loss. It was decided to compensate for this loss by heating the coker walls and by preheating the entering gas streams. Since the heat-transfer coefficient of coal particles to gas is quite low under these conditions, preheating should reduce the large temperature driving force needed to

TABLE I

* Positions 1, 2, 3, and 4 are 38, 23, 8, and 2 inches above the sieve plate on Runs A, B, C, D, and E. (Stationary well). Positions 1, 2, and 3 are 32, 13, and 2 inches above sieve plate on Runs K, L, M, N, O, P, Q, S, T, and U. (Probes).

†The coal-feed rate is an average value for each series of runs.

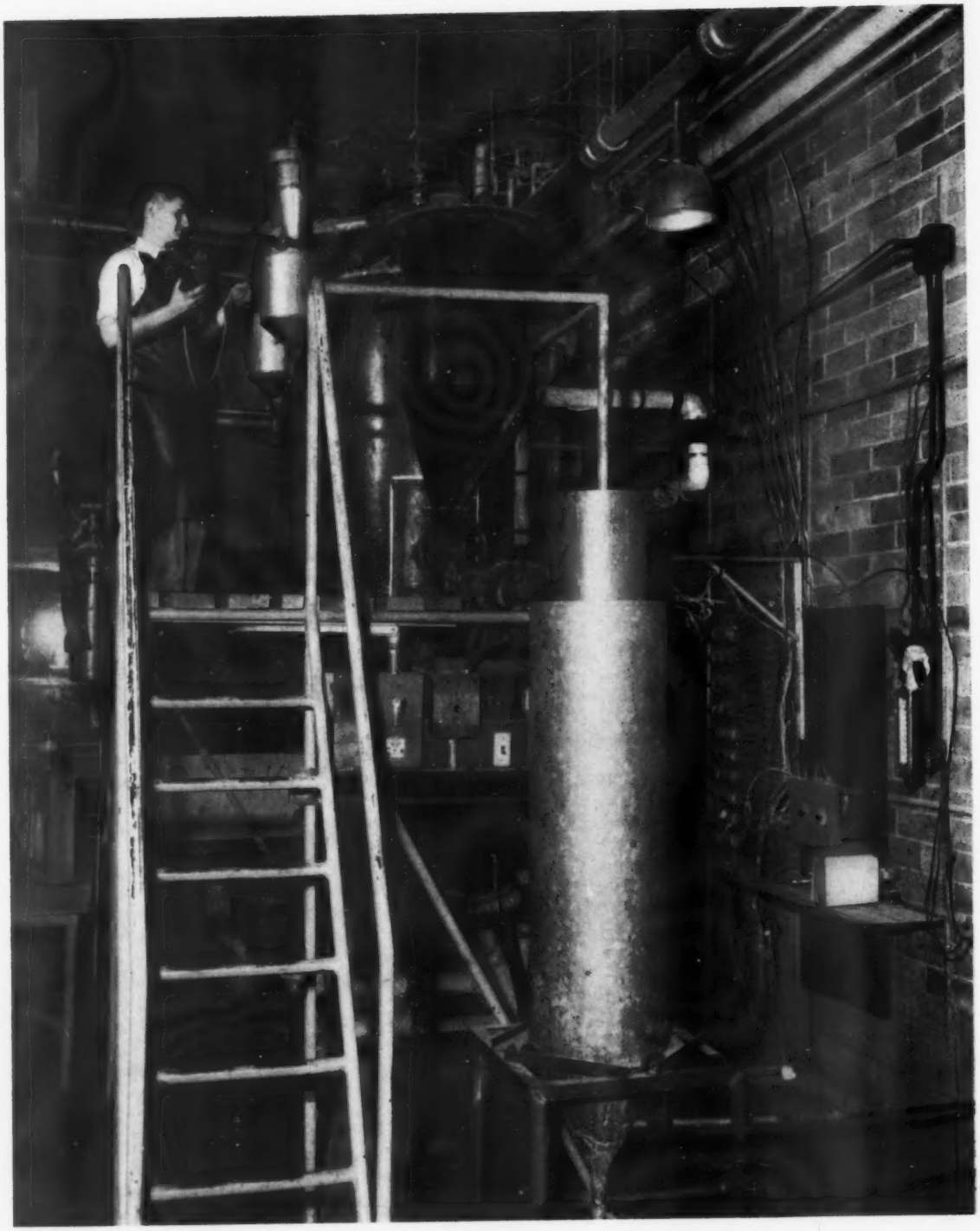

FIG. 4. COMPLETE GASIFICATION PILOT-PLANT INSTALLATION

produce the desired temperature of the fluidized bed, thus preventing clinkering. Under these conditions, runs S through U were made. Unfortunately, the preheaters proved insufficient to preheat the streams to the necessary level and, as a result, clinkering occurred. However, with sufficient preheating, clinkering should be helped considerably or eliminated.

Performance of Pilot Plant

The hope that a study of these data would indicate trends in operation was not realized because of the preliminary nature of the results, which did not afford a complete range of data for analysis. However, the following tendencies were noted. In the gasifier, an increase in steam content seemed to increase the ratio of hydrogen to carbon monoxide, along with the hydrogen content. In the burner section, the same trend was noticed. In the coker the hydrogen-to-carbon monoxide ratio seemed to increase with water content, but the hydrogen content appeared to be constant. Temperature effects were quite varied. Although an over-all hydrogen-to-carbon monoxide ratio maximum was apparently reached at a burner temperature of 1400° F, test results to date do not warrant prediction of the over-all effect. In general the results agree with the chemistry of gasification.

Industrial Comparison

Although not enough data are available to allow a true economic estimate of the cost of synthesis gas as well as the optimum operating conditions, a comparison can be made with other units to determine improvements and the feasibility of the industrial plant. Two such plants are compared with the University of Washington pilot plant in Table II.

Conclusions

A three-unit fluidized-bed pilot plant for studying the gasification of Washington coal has been constructed and put into operation.

In this fluidized system the transfer of coal or coke was found to be a function of the number, diameter, and spacing of transfer holes.

Although the reactors retain some of their individuality, as noted by varying hydrogen-to-carbon monoxide ratio, the individual reactors do not operate completely as separate units, since nitrogen appears in the gasifier exit gas and large amounts of water appear in the burner exit gas.

Clinkers, which result from the collision of hot coke particles in the fluidized bed of the burner, occur when temperature recorded by the thermocouple exceeds 1600° F. Proper preheating should prevent this.

Although the oxygen consumption of the pilot plant is quite high, the plant exhibits high thermal, carbon, and ash efficiencies. Carbon efficiencies and size of fly dust can be altered since they depend primarily upon size of coal feed and gas velocity through the bed.

TABLE II

INDUSTRIAL COMPARISON

WASHINGTON COAL IN THREE-UNIT FLUIDIZED-BED PILOT PLANT

LOCATION: UNIVERSITY OF WASHINGTON SEATTLE, WASH.	RUNS K-N	RUNS S-U
Burner Temperature (°F)	1400	1470
Carbon Fed: #/1000 cu ft ($CO+H_2$)	39	36
Oxygen: cu ft/1000 cu ft ($CO+H_2$)	660	570
Oxygen: #/# of dry ash-free coal	1.1	1.0
Steam: #/1000 cu ft ($CO+H_2$)	155	41
Steam: #/# of dry ash-free coal	1.3	0.9
H_2/CO Ratio	1.1	1.2
Yield of ($CO+H_2$): cu ft/# of dry ash-free coal	20.5	21.6
Synthesis Gas Production: cu ft/sq ft/hr	190	250
Total Ash in Fly Dust (%)	32.4	30.2
Carbon Efficiency (%)	88	86
Thermal Efficiency (%)	69	87

WINKLER GENERATOR USING BROWN COAL

LOCATION	LEUNA	BOHLEN
Fuel-Bed Temperature (°F)	1600	1472
Carbon: #/1000 cu ft ($CO+H_2$)	29.2	34.4
Coal: #/1000 cu ft ($CO+H_2$)	53.5	49.4
Oxygen: cu ft/1000 cu ft ($CO+H_2$)	366	324
Steam: #/1000 cu ft ($CO+H_2$)	26.3	53.5
H_2/CO Ratio	1.1	1.5
Synthesis Gas Production: cu ft/sq ft/hr	5290	3270
Ash in Fly Dust (%)	29	43
Carbon Efficiency (%)	86.5	68.6
Thermal Efficiency (%)	52	56

POWDERED COAL GASIFICATION PILOT PLANT USING COLORADO SUBBITUMINOUS COAL

LOCATION	MORGANTOWN, W. VA.
Temperature (°F)	1635
Coal: #/1000 cu ft ($CO+H_2$)	45.7
Oxygen: #/# of dry ash-free coal	0.64
Oxygen: cu ft/1000 cu ft ($CO+H_2$)	310
Steam: #/# of dry ash-free coal	0.16
Steam: #/1000 cu ft ($CO+H_2$)	6.51
H_2/CO Ratio	0.67
Yield of ($CO+H_2$): cu ft/# of dry ash-free coal	24.7
Synthesis Gas Production: cu ft/cu ft space/hr	915
Total Ash in Residue (%)	36.3
Carbon Efficiency (%)	84.3
Thermal Efficiency (%)	72.8

In order to evaluate the degree of cross mixing in the reactor, and to establish optimum operating conditions, the project efforts are now being directed toward a thermodynamic-kinetic type of study. By this means the theoretical compositions may be obtained and used to guide pilot-plant operation.

(Continued on page 28)

FLAT-EARTH TRANSFORMATION AND ITS MATHEMATICAL INTERPRETATION FROM SPHERICAL-EARTH GEOMETRY

R. N. GHOSE*

R. N. Ghose

The problem of determining the field intensity of very-high-frequency and ultra-high-frequency radio waves in a region well beyond the line of sight, has been of great interest during recent years. The theory which has received the most attention to date is one which, by modifying the index of refraction, adapts a transformation of space so as to treat the earth as flat, while the electromagnetic rays are curved. Although this transformation simplifies the problem by rendering a cylindrical symmetry about the transmitting antenna, the solution under such a transformation will not be valid for large distances and for high antennas.

In the present analysis, an attempt has been made to compare the theoretical field intensity as derived from the aforesaid "flat-earth" approximation with that which is to be expected from the "spherical-earth" geometry for arbitrarily nonhomogeneous atmospheres. The Mode-Theory of propagation of radio waves is considered for the purpose of comparison, and, since in Mode-Theory eigenvalues form the predominant factor in determining the total field intensity, a comparative study of the eigenvalues for a linear distribution of refractive index and "flat-earth" transformation and for exponential distribution of refractive index with "spherical earth" geometry, has been made.

Comparative Study

When an electromagnetic wave progresses through the nonhomogeneous dielectric medium constituting the atmosphere, the wave is bent and the radius of curvature is given by

$$R_1 = -2e_0/(\partial e/\partial h) \qquad (1)$$

where e_0 is the dielectric constant of the air at the surface of the earth and $(\partial e/\partial h)$ is the vertical gradient of dielectric constant above the earth's surface. In the troposphere, where the conductivity of the medium is essentially zero, the radius of curvature can also be expressed in terms of the refractive index n, where $n=\sqrt{e}$, and, therefore,

$$R_1 = -2n_0^2/(\partial n^2/\partial h) = (-n_0^2/n)/(\partial n/\partial h). \qquad (2)$$

The normal value of n_0 is of the order of 1.0003, and $n_0 > n > 1$, so $n_0^2/n \simeq 1$. Therefore,†

$$1/R_1 \simeq -\partial n/\partial h = -dn/dh\,. \qquad (3)$$

In an homogeneous atmosphere $n_0 = n$, and $\partial n/\partial h = 0$, so R_1 is infinite, which means that the rays will not be bent. If such a ray is emerging upward from a transmitting antenna placed over the surface of the earth, the curvature of the earth and the ray will diverge, and the distance between them will increase, as shown in Fig. 1.

It is also apparent[1] that, for any other type of atmosphere where $\partial n/\partial h \neq 0$, the electromagnetic ray, or the contour of the equiphase points of the wave propagating from the transmitting antenna placed over the spherical earth, will be curved as shown in Fig. 2, and the path of the curved ray and the curvature of the earth may not diverge. In most cases, for the purpose of the mathematical analysis, the relative distance between the ray and the curvature of the earth, rather than their absolute location and orientation in space, is important. Thus, if the earth is regarded as flat and the rays are bent upward, the situation is not changed essentially. However, it is to be assumed that the distance between the curvature of the earth and the rays is kept the same in both cases. To account for the

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†If a horizontal stratification is assumed, n becomes a function of h alone, and $\partial n/\partial h = dn/dh$.

upward bending of the ray, a fictitious distribution of the refractive index is usually assumed. Since the curvature of the ray is equal to the reciprocal of the negative gradient of the refractive index, it is necessary, in order that the difference between R_1 and the earth's radius be the same under flat-earth condition as it is in the spherical-earth situation, that the distribution of the fictitious refractive index should be equal to the reciprocal of the earth's radius plus the vertical gradient of the refractive index.

Thus if N represents the modified refractive index, it is related to n by

$$dN/dh = 1/a + dn/dh\,, \tag{4}$$

where a is the radius of the earth.

Or,

$$N = h/a + n + \text{a constant}, \tag{5}$$

and, at $h=0$, $N=n_0$, and thus

$$N = n_0 + h/a\,. \tag{6}$$

Thus, by transformation of the form as used in Eq 6, the earth can be regarded as flat, and the cylindrical symmetry about the radiating antenna, arising from such transformation, can be utilized for analysis.

The general idea of regarding the earth as flat and modifying the index of refraction can also be justified, following the method used by Pryce.[2] Let r, θ, and ϕ be the spherical co-ordinates of a point, the origin of the system being at the centre of the earth, and let the new co-ordinates x_1, x_2, and z, be defined by

$$\left.\begin{aligned} x_1 &= a \sin\theta \cos\phi\,, \\ x_2 &= a \sin\theta \sin\phi\,, \\ z &= r - a\,, \end{aligned}\right\} \tag{7}$$

where θ is the angle subtended at the centre of the earth by radial lines through the earth's centre, connecting the transmitting antenna and the point under consideration.

The element of the arc, dl, is given by

$$(dl)^2 = (1+z/a)^2\,[dx_1^2 + dx_2^2 + (x_1 dx_1 + x_2 dx_2)/(a^2 - x_1^2 - x_2^2)] + dz^2\,. \tag{8}$$

In general, only the region for which x_1/a and x_2/a are sufficiently small is of any interest, and thus their square and higher powers can be neglected. Thus,

$$dl^2 = \eta^2(dx_1^2 + dx_2^2) + dz^2\,, \tag{9}$$

where

$$\eta = 1 + z/a\,. \tag{10}$$

This transformation enables one to set up the problem of a radiating antenna over the surface of the earth in a cylindrical co-ordinate system with the antenna at $P_1(0, 0, b)$ when b is the height of the transmitting antenna above the earth's surface, as in Fig. 3. The electromagnetic field for such a system can be derived from the Hertzian potential, ψ, which satisfies the wave equation,

$$(\nabla^2 + k^2)\psi = 0\,, \tag{11}$$

where $k = \omega^2\mu\epsilon$,

$\omega = 2\pi$ frequency,

μ = permeability of the medium,

ϵ = dielectric constant of the medium,

and a time factor of $e^{j\omega t}$ is assumed.

This wave equation can be solved subject to the following two boundary conditions:

$\psi \longrightarrow (1/R)\ e^{-jkR}$, where R is a short distance from the antenna or source, and

ψ should behave as an outgoing wave at large heights.

Assuming a symmetry in the ϕ direction and a product solution of the form, $\psi = R(r)\,H(h)$, two equations are obtained (in the cylindrical co-ordinate system):

$$(1/R)(d^2R/dr^2) + (1/R)(dR/dr) + K_m^2 = 0\,, \tag{12}$$

$$(1/H)(d^2H/dh^2) + k^2N^2 - K_m^2 = 0\,. \tag{13}$$

Here, K_m is the separation constant and is a function of the propagation constant, $2\pi/\lambda$, and the modified refractive index, N.

The solution of Eq 12 is

$$R(r) = K_1 J_0\,(K_m r), \tag{14}$$

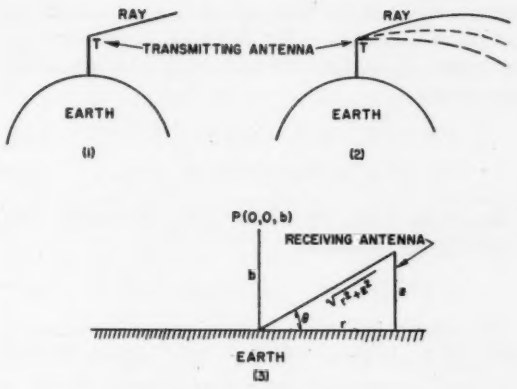

FIG. 1. HOMOGENEOUS ATMOSPHERE
$(dn/dh = 0)$

FIG. 2. NONHOMOGENEOUS ATMOSPHERE
$(dn/dh \neq 0)$
(Nonuniform dielectric medium causes rays to bend according to Snell's Law.)

FIG. 3. CYLINDRICAL-EARTH GEOMETRY WITH FLAT-EARTH TRANFORMATION
(z=height of receiving antenna)

where r is the radial distance from the transmitter, and K_1 is a constant. For this type of problem the eigenvalue K_m is determined from Eq 13 which can be written*

$$d^2H/dh^2+[k^2n^2\,(1+h/a)^2-K_m^2]H=0\,, \qquad (15)$$

$$d^2H/dh^2+[k^2n^2-K_m^2+2k^2n^2h/a]H=0\,. \qquad (16)$$

Since[3] $K_m\simeq kn_0$, $n\simeq 1\simeq n_0$, and $k^2n^2\simeq K_m^2$, this equation can be written

$$d^2H/dh^2+[k^2n^2-K_m^2+2K_m^2h/a]\,H=0\,. \qquad (17)$$

It is interesting to compare this equation with the corresponding equation for the spherical-earth geometry. Assuming again a symmetry in the ϕ direction, the corresponding "height-gain equation" in the spherical co-ordinate system can be written as

$$d^2Q/dh^2+[k^2n^2-K_m^2a^2/(a+h)^2]Q=0\,, \qquad (18)$$

where $Q=U(h)\,(h+a)$, $K_m^2a^2$ is the separation constant similar to K_m, and n is the same as in Eq 16.

Both Eq 15 and 18 can be written in generalized form, as follows:

$$d^2y/dx^2+\,[k^2n^2-\lambda(K_m,\,h)]\,y=0\,, \qquad (19)$$

where $\lambda(K_m, h)$ is a polynomial in h, and can be represented as

$$\lambda(K_m,\,h)=a_0+a_1h+a_2h^2+a_3h^3\,\ldots\,, \qquad (20)$$

assuming that $a_0=-K_m^2$, and $a_1=2K_m^2\,h/a$ .....

Then, assuming a first-order approximation of the polynomial, $\lambda(K_m, h)$, Eq 18 can be written as

$$d^2Q/dh^2+[k^2n^2-K_m^2+2K_m^2h/a]\,Q=0\,, \qquad (21)$$

which is essentially the same as Eq 17. Thus the first-order approximation of the coefficient of $Q(h)$ in the differential equation for the height-gain function gives rise to an eigenvalue problem which is identically the same as one obtained from the transformation of space by using the fictitious modified refractive index.

Equation 17 is a Ricatti equation, the general solution of which is a linear combination of the Hankel functions of one-third order of two different types. The resultant field intensity by this first-order approximation, which is also equivalent to the flat-earth transformation, has been worked out in detail.[2] Obvious disadvantages of the first-order approximation, along with the linear approximation of the refractive index distribution as used in the aforesaid analysis, are the following:

(1) Linearly decreasing index of refraction with height is physically unrealizable, as there exists, according to this approximation, a height where $n(h)$ is less than unity and even negative. Such a situation cannot exist in a charge-free region.

(2) The parameter, $\lambda(h)$, is unbounded with increasing height when a first-order approximation is made. This is contrary to the original expression of $\lambda(h)$ as shown in Eq 19. Various methods for the field-strength calculation were developed for different distributions of refractive index on the basis of the flat-earth approximation. But, probably because of the unbounded nature of the coefficient $\lambda(h)$, when $Q(h)$, or $U(h)$ is obtained from these analyses for any mode considered separately, it approaches infinity as h approaches infinity. It is also obvious from the method used by Pryce in order to justify the flat-earth transformation, and also from Eq 9 and 21, that any solution with such approximations can be justified only for low heights. In fact, the approximate solution diverges from the actual solution with increasing height.

It can be seen, from the comparative study of the wave propagation with flat-earth approximation and with spherical-earth geometry, that the asymptotic values of factors similar to R in Eq 14, which can be termed distance-attenuation factors, are the same in both cases. Furthermore, for a region close to the surface of the earth, the height-gain factors corresponding to U are almost the same in both cases. Thus the only important difference in the numerical values of the field intensity in the diffraction zone,* as calculated from the two theories, will depend on the difference of their eigenvalues. In spherical-earth geometry, the imaginary part,[3] of K_m has the following value:

$$\text{Im}\,K_m=k^{1/3}\,(n_0^2-a\alpha n_0)^{2/3}\times 0.92788\times 1.732/a^{2/3}, \qquad (22)$$

where α is the gradient of the index of refraction at and near the surface of the earth, and n_0 is the surface refractive index.

The corresponding value of the imaginary part[4] of K_m with "flat-earth" approximation† is

$$\text{Im}\,(K_m)\simeq\{0.433-k^{1/3}[(9\pi/4)/(1-a\alpha n_0)]^{2/3}\}/a^{2/3}. \qquad (23)$$

Since the imaginary part of K_m predominates the expression for the electromagnetic field in the diffraction zone, the comparison of Eq 22 with 23 shows

*Since h/a is very small, only first-order approximation, involving the first power of h in the power series expansion of $(1+h/a)^2$, can be used.

*The diffraction zone is defined as the region beyond the line-of-sight of the transmitting antenna.

†These imaginary parts of K_m refer to Im (K_m) for the first or dominant mode, contributing to the distant-field.

that eigenvalues and the field intensities according to the "spherical-earth" geometry and the "flat-earth" approximation, are comparable.

Conclusion

An attempt has been made to show that the "flat-earth" approximation for determining the electric field intensity at a point from a radiating antenna is only the first-order approximation of the "spherical-earth" geometry where no approximation is made and the earth is considered as a sphere, particularly insofar as the eigenvalues are concerned. From the comparative study of the eigenvalues, it can be seen that for the near-diffraction-zone, which may be defined as the nearest zone beyond the line-of-sight of the transmitting antenna, and for small height of the transmitting and receiving antennas, the resultant field intensities are comparable in "flat-earth" transformation with those in "spherical-earth" geometry because the "height-gain" factor and the "distance attenuation" factor for both the cases are comparable for the near-diffraction-zone. However, this approximation will not be valid for the far-diffraction-zone or for the region far beyond the line-of-sight.

ACKNOWLEDGMENT

The author is indebted to Professors W. E. Rogers and H. M. Swarm of the Electrical Engineering Department of the University of Washington and to Dr. E. C. Jordan of the University of Illinois for their valuable suggestions.

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Cooperative Streamflow Project

In June, 1952, the Bonneville Power Administration entered an agreement with the Civil Engineering Department and the Department of Meteorology and Climatology of the University of Washington for a streamflow research program. The University was to undertake the study of specific forecasting problems as required for power operation.

The efficient and economical operation of the Federal power facilities in the Northwest requires a detailed and continuous study of the climatic and hydrological phenomena prevailing in the Columbia River Basin. With additional storage reservoirs and power generation continually being developed on the Columbia River and major tributaries, the problem of accurate and continuous evaluation of the power potential of the river assumes increased importance. Advance warning of the magnitude and timing of changes in the flow is necessary for the efficient operation of the BPA and inter-connected systems. The proposed research program was therefore set up to develop procedures whereby increased flow from snowmelt or precipitation could be forecast for short periods from weather records or from forecasts of weather on many of the major tributaries to the Columbia River Basin.

The hydrologic research program was divided into three projects as follows:

(1) Short-range forecasts of snowmelt runoff at selected points on tributaries entering the upper Columbia.
(2) Short-range forecasts of runoff from precipitation at selected points on tributaries entering the lower Columbia.
(3) The relationship of temperature, precipitation and streamflow on a monthly basis for selected tributaries.

The University was represented in this work by Dr. Phil E. Church, head of the Department of Meteorology, and Professor Thomas H. Campbell of the Department of Civil Engineering, the Bonneville Power Administration, by Milton S. Sachs, Chief of the Water Utilization Section, and the Geological Survey, by Staff Engineer C. C. McDonald and Hydraulic Engineer Wilbur Simons. Two undergraduate students and two graduate students worked on the program.

Project No. 1 was carried on chiefly by Mr. Donald Makela under the supervision of Dr. Church and Professor Campbell. The final report is entitled "Short-term Streamflow Prediction from Snow Melt, Middle Fork Flathead River, Montana."

Work under Project No. 2 was carried on by Students Ernest Pogge, Robert W. Okey and Donald R. Makela under the supervision of Professor Campbell. The following six reports, presenting forecasting procedures on several tributaries, were completed: five short-term streamflow predictions from precipitation data at (1) White Salmon River at Husum and Underwood, Wash., (2) Klickitat River at Glenwood and Pitt, Wash., (3) Hood River at Hood River, Ore., (4) John Day River at McDonald's Ferry, (5) Wind River near Carson, Wash., and a pilot report on short-term streamflow prediction from precipitation data, Sanpoil River near Keller, Wash.

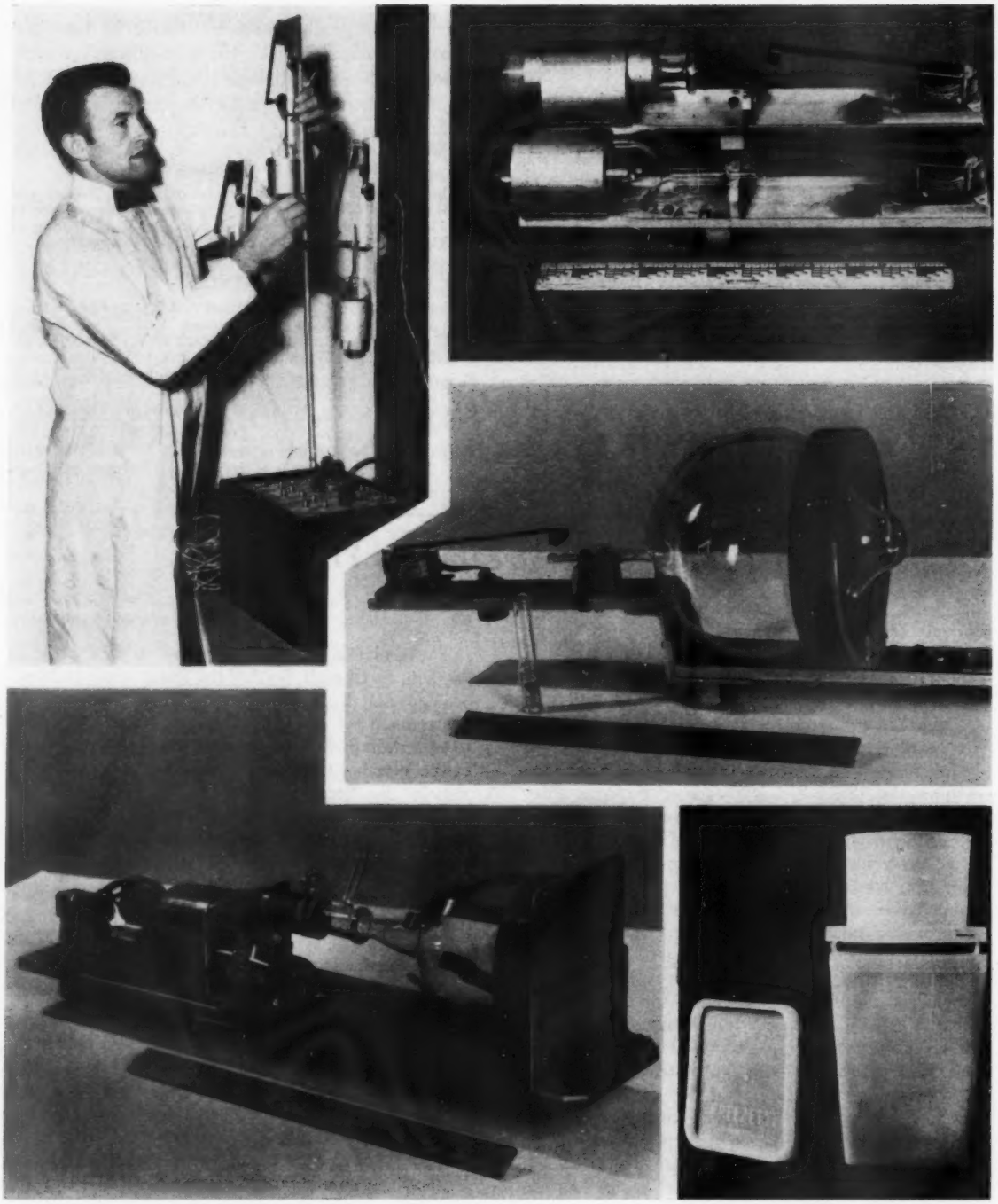

FIGURE 1

(a) *Lower left:* Air sampler actuated by an ordinary windshield-wiper motor.
(b) *Upper right above:* Air sampler actuated by a solenoid and hammer which allows hypodermic plunger to drop.
below: Air sampler actuated by solenoid and hammer which breaks capillary tube.
(c) *Right center:* Air sampler solenoid-operated, which employs a 2-liter flask.
(d) *Upper left:* Vaughn R. Ransom, pharmacologist, setting up a typical sampling installation.
(e) *Lower right:* Exploded view of plastic dirt-fall jar and cap used for shipping.

INSTRUMENTATION IN INDUSTRIAL HYGIENE AND AIR POLLUTION DEVELOPED AT THE ENVIRONMENTAL RESEARCH LABORATORY

ROSS N. KUSIAN

Director, Environmental Research Laboratory

Part I: Field Sampling Instruments

R. N. Kusian

The development of basic instruments has lagged in the new and rapidly expanding fields of industrial hygiene and air pollution because of the limited market possibilities and lack of standardized techniques.

In May, 1954, the Institute of Public Health and the School of Health, University of Michigan, cosponsored a symposium on instrumentation in industrial hygiene, bringing together instrument makers, users, and experts in the field of instruments. Its purpose was to exhibit, inform, and discuss the needs for improvement and development of new instruments for use in industrial hygiene and air-pollution studies. The symposium, together with a resulting encyclopedic type of book which grew out of the meeting, has filled a long-felt need as evidenced by the enthusiastic response from both manufacturers and users of such equipment.

The Environmental Research Laboratory participated in the symposium by exhibiting several items that had been developed for special problems encountered in the work of the Laboratory. In addition, photographs of larger equipment were displayed.

Credit for development of the items discussed in this article is difficult to assign to specific staff members, for they are products of a team research unit. Mario Storlazzi, industrial hygiene chemist; Arthur S. Gorai, industrial hygiene engineer; Vaughn R. Ransom, pharmacologist; John B. Pate, chemist; and James A. Ritchie and John Zinkernagel, engineering experiment station machinists, actively participated in the development of one or more of these instruments.

Remote-Control Air Sampler: Motor Operated

In a project for the U. S. Air Force undertaken for the purpose of evaluating personnel exposure to rocket exhaust gases in and near test and operational rocket facilities, measurements of peak concentrations of exhaust gases were needed in the immediate area of the jet stream from the rocket. Because of the turbulence, personnel protected with safety suits and masks could not stay in the area during rocket firing, even though they might not be in a high-temperature zone. Long sampling tubes would not be satisfactory because of the time lag necessary for purging the lines.

The first instrument designed to obtain the rocket exhaust gases was the motor-operated, remote-control air sampler shown in Fig. 1-a. This instrument collected a 500-ml atmospheric sample which could be actuated by remote control from an explosion-protected observation booth.

An evacuated 500-ml Shepherd flask with a rotating cap is attached through a flexible coupling to the shaft of an ordinary electric-powered windshield-wiper motor. The motor is operated by remote control through a relay system (Fig. 2). Two contact cams and a microswitch will stop the motor in the open and closed positions of the cap.

The sampler, 5 in. by 5 in. by 20 in., weighs approximately 5 lb. Construction is mainly of aluminum, and power is supplied by a 6-v automobile battery.

Remote-Control Air Sampler: Solenoid Operated

Several problems arose as this rocket exhaust-gas sampling continued. First, the necessity of taking numerous samples over a large area required a large number of samplers and a complicated wiring system. Second, the flasks had to be evacuated in the field just prior to the test and properly placed in the mountings. The time required for this step in the process interfered with the rocket test schedules. Third, because the rocket-testing areas were scattered all over the United States, shipping of the flasks to the Environmental Research Laboratory for analyses needed to be as simple as possible.

Three types of solenoid-actuated devices (Figs. 1-b and 1-c) were developed to overcome some of the problems. Instruments similar in principle have been reported by Setterlind[1] and the U.S. Bureau of Mines.[2,3]

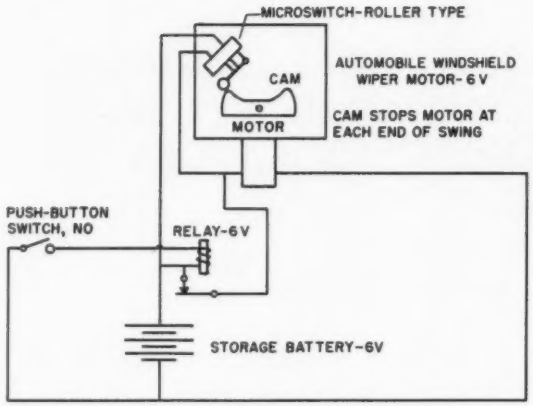

FIG. 2. WIRING DIAGRAM OF REMOTE-CONTROL, MOTOR-OPERATED AIR SAMPLER

The sample containers are held in solenoid-mounted frames. A small hammer mounted on the solenoid strikes the arm supporting the vertically mounted syringe or breaks the capillary tube (Fig. 1-d), according to the type of containers. Actuation is done through a multiple switching box (Fig. 1-d and Fig. 3) which permits collection of a large number of samples over a wide area at different times and intervals. Containers are sealed, immediately after sampling, by rubber policemen.

The control box handles a maximum of 36 small samplers, using 50-ml syringes or 235-ml bottles with 2-mm capillary necks fabricated from 51-mm Pyrex tubing. The larger sampler holds round-bottom Pyrex flasks up to two liters in size (Fig. 1-c).

The sampler for syringes and small bottles weighs approximately 1½ lb and is about 2 in. by 3 in. by 14 in. The sampler for larger flasks weighs approximately 3 lb and is about 7 in. by 7 in. by 24 in. The control box is approximately one cubic foot in size and weighs 10 lb. Power is supplied from either a 115-v a-c source or by four 45-v radio 'B" batteries.

The advantage of the 235-ml bottles and the larger flasks is that they can be evacuated and sealed in the laboratory before shipping. During the tests they were easily placed in the sampler between rocket firings, and were easily sealed by means of a rubber policeman for return to the laboratory. The syringe is used in the Patty and Petty technique[4] for the determination of oxides of nitrogen. In this method the reagents are already in the syringe at the time of sampling. Later, colorimetric determinations are made in the field.

Plastic Dirt-Fall Jar

A basic technique for determining the amount of air pollution in a certain area is to put out a dirt-fall jar which is nothing more than a settling jar. Everything from ½-gallon pickle jars to copper containers

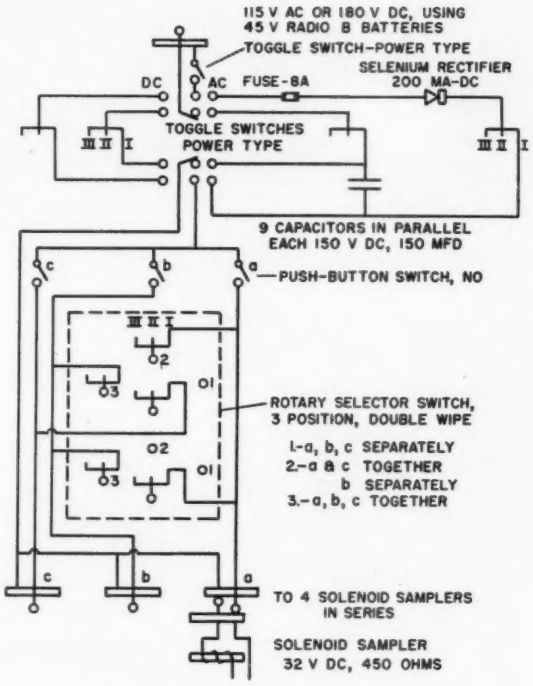

FIG. 3. WIRING DIAGRAM FOR REMOTE-CONTROL, SOLENOID-OPERATED AIR SAMPLER

with louvered openings has been used for this type of work. The amount of dirt (usually separated into combustibles and non-combustibles) is weighed and is reported as a rate of dirt-fall in units of tons per square mile per month.

During winter months the water used to trap the settled dirt freezes and either breaks or ruptures the container. If anti-freezes are added, the analytical procedures are much more difficult because of the residues.

Several types of glass jars were tried before it was decided to try plastic food containers used for storing frozen foods. Because no jar with satisfactory dimensions was commercially available, variations were tested by welding funnels into the tops of different jars. The present jar, as shown in Fig. 1-e, consists of a two-quart "Freezette" as the body of the container, with the funnel section cut from the top portion of a three-pint "Polyflex Decanter." These containers may be obtained from most department notion stores at a cost of about $1.80 per set. The top piece of the decanter is welded to the slip-cover of the square freezette by using an ordinary electric soldering iron. Slivers of the material may be used as a filler rod when necessary. This type of jar is being used in air-pollution studies currently under way in Seattle, Tacoma, and Longview.

Dimensions of the dirt-fall jars are 3¾ by 3¾ in. at the base, 4⅞ by 4⅞ in. at the top of the square portion, and 4⅛ in. diameter at the top of the funnel section. Over-all height is 10½ in., and the height of the square section is 6⅜ in. If no evaporation is assumed, the container will hold 8.8 in. of rainfall. These dimensions do not quite conform to the forthcoming recommendations of the Air Pollution Control Association's Committee on Air Pollution Measurements which will tentatively specify that the diameter of the opening be $5 \pm \frac{1}{2}$ in., and that the height be two to three times the diameter. However, a slightly larger funnel section can be fabricated in order to satisfy these recommendations.

The advantage of these containers is that they cannot be broken by freezing, shipping, or small boys equipped with BB guns or slingshots.

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Notes and Comments

ENGINEERS IN THE NEWS

The Pacific Section of TAPPI held its 8th Annual Seminar at Bagley Hall, September 27-28. Chairman of the committee on arrangements was **J. L. McCarthy,** Professor of Chemical Engineering. The speaker was **Dr. Herbert F. Rance,** Manager of Research and Development for Wiggins, Teape, & Co., Ltd. This seminar was repeated at Portland, September 30-October 1. Dr. McCarthy attended the meeting of the American Chemical Society in New York, September 13-17 and participated in the "Discussion of Cellulose Dyeing." He also co-authored the paper on "Alkiline Cleavage of Lignin," presented by **Douglas Glennie,** graduate student in organic chemistry, September 10, before the Canadian Institute of Chemistry at Vancouver, B. C.

R. G. Tyler, recently retired Professor of Sanitary Engineering, presented a film on "Diffusion of Sewage Effluents Discharged into Puget Sound" at the 27th Annual Meeting of the Federation of Sewage and Industrial Wastes Associations held in Cincinnati, October 11-14. The film shows operation of the model built several years ago by the Department of Oceanography to reproduce the currents and mixing in Puget Sound.

G. S. Smith, Professor of Electrical Engineering, read a paper entitled "Use of the Heat Pump for Digester Heating" at the AIEE meeting at Los Angeles, June 23-24.

At the same meeting, **F. R. Bergseth,** Associate Professor of Electrical Engineering presented a paper on "An Electronic Distance Relay Using a Phase-Discriminating Principle."

R. A. Hechtman, Professor of Structural Research, will read a paper on "Lateral Buckling of Beams," October 19, before the National ASCE meeting to be held in New York, and another paper, "Welded Reinforcement of Openings," October 21, before the Ship Structures Committee in Washington, D. C.

E. E. Day, Professor of Mechanical Engineering, has been named to receive the Pi Tau Sigma Gold Medal Award, presented by the Board of Honors of the ASME, at the Society's annual meeting, Nov. 29 to Dec. 3, in New York. The award is presented annually to a mechanical engineer for outstanding achievement in his field within ten years of his graduation from an accredited American university or college.

Seven University professors participated in the Boeing Summer Faculty Program. They were Professors **Thomas H. Campbell,** Civil Engineering Department; **James H. Fisher,** Electrical Engineering Department; **Harold M. Hendrickson, Blake D. Mills Jr., Robert P. Krause, Berl W. Owens** and **Lawrence B. Zylstra** of the Mechanical Engineering Department; **Harold C. Martin** and **Raymond C. Weikel** of the Aeronautical Engineering Department.

H. C. Martin, Professor of Aeronautical Engineering, will be in New York for the ASCE meeting, to read a paper on "Non-Linear Beam Deflections" before the Engineering Mechanics Division on October 18.

F. B. Farquharson, Professor of Civil Engineering and Director of the Engineering Experiment Station, will also attend the ASCE convention and will meet with the ASCE Committee on Wind Forces and the ASCE Task Committee on Civil Engineering Curricula.

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NEW TRENDS IN CERAMICS

(Continued from page 7)

now glass coated on the inside, as are many stacks where acid fumes are encountered. Coatings also protect tubes of immersion-type thermocouples.

A new abrasive cloth has been developed recently for finishing jobs on wood or metal. An open mesh design allows the removed particles to flow through the cloth and not clog the abrasive teeth. It can be used on both sides, wet or dry, flat or folded, and by machine or hand. Its life is 10 to 15 times that of most ordinary coated papers.[18]

Enamel coatings are also used in pump housing interiors for heavy duty industrial applications. Another development is a ceramic plunger for proportioning pumps, which is resistant to high-pressure corrosive or abrasive conditions. Sizes ranging from $\frac{7}{16}$ in. to 5 in. diameter are used for such applications as moving cement, mud, salt water, etc.[19]

Several new types of thermal insulation are now available. Besides glass fibers there are new high-temperature insulations capable of withstanding 2000 or 2500° F. In addition to their insulating values, they have extreme chemical stability and are available in many forms. Tests have shown that the time required to heat a furnace to 2500° F is reduced 50 per cent, and that 30 per cent less electrical power is required to maintain furnace equilibrium at that temperature when a lining of refractory brick is replaced with the fibrous material.[20]

New type ceramic bonds have been made available in grinding wheels for all types of performance, especially in precision and semi-precision grinding. Excellent results have been obtained in wheels for tool and cutter grinding, crush grinding, and surface grinding. Cylindrical and centerless grinding results also are improved. Besides the improvement in results, the life of the wheel has been tripled.[21]

Metallurgical Engineering

New refractories for the metallurgical industries make possible uses up to 4600° F in limited applications. Stabilized zirconia has several uses, combining its extreme refractoriness, low thermal conductivity, and thermal shock resistance. It can be used in furnace linings or kiln furniture, and for thermal insulation, as well as for electric furnace heating elements, especially in ultra-high-frequency induction furnaces where it can operate at 4000° F for reasonable periods.[22]

Bonded SiC is also used in many metallurgical applications. In holding parts for high-temperature brazing, in cycles of cold to 2100° F to cold in 1½ hours, its life is double that of metals and it is cheaper than the parts replaced. It is also used as linings for crucibles and retorts.[23]

New "cermets" of borides and aluminides in combination with zirconium, chromium, and molybdenum have recently been discovered. These materials polish to a high luster, have electrical and thermal conditions in the range of pure metals, have a positive temperature coefficient of resistivity at room temperature, and high melting point—up to 500° F.[24]

Miscellaneous Uses

A new method for the manufacture of alumina abrasives has been developed to give a closer control over crystal size. Instead of the usual preliminary cooling in the furnace, the molten bauxite is cast into water-cooled steel spheres or other molds where the rate of cooling can be very closely controlled. This, of course, results in a more uniform product that makes better grinding wheels and coated abrasives.

Glass windows are now being manufactured for use near X-ray and atomic radiation. Windows, each weighing as much as 10 tons or more, are highly absorptive and non-browning. They may be as thick as 20 in. A glass is being made in Seattle containing the equivalent of 85 per cent lead and having 80 per cent light transmission in the visible region of the spectrum.

Glass is also being made for use in dosimeters to replace the standard film packs used in the past.

Photosensitive glass is available that can be formed into intricate patterns. The glass is exposed to a differential chemical etch, similar to the process of etching metals, but much faster. It makes possible the perforating of glass with holes of any shape and size down to a few thousandths of an inch, which may be spaced so as to include up to several thousand holes per square inch.[25]

Conclusion

Just a few of the products recently developed by the ceramic industry have been described here. Many more are available, and continuing research should ultimately lead to improved ceramic methods and products to assist other branches of industry and engineering and, eventually, to improve our standards of living.

The ceramic industry is undoubtedly on the threshold of an era in which the need of its products will be even more widespread than it is today, and in which the ceramic engineer will play an increasingly important part. To train the many new engineers for this field in which, even today, the demand far exceeds the supply, will be the task of our ceramic engineering departments.

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SCHOOL FOR TEACHERS OF DRIVING

The Basic Course in Driver Education and Training for High School Teachers was given for the eighth year at More Hall, Aug. 30-Sept. 3. Thirty-one registrants included, besides 12 high school teachers, representatives of commercial schools of driving, members of the University Safety Division, State Highway Department, etc. One man from New Zealand and another from Prince George, B. C., attended the course.

Professor Amos E. Neyhart, Administrative Head, Institute of Public Safety, Pennsylvania State College, who is also Consultant on Road Training of the A.A.A., again was special instructor of these sessions.

A number of requests have been received for a repetition of the advanced course which was offered in 1952. Professor Fred H. Rhodes, Jr., of the Civil Engineering Department, is general director.

Engineering Research Dividends

Recent theses submitted for advanced degrees from the College of Engineering, University of Washington, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station, University of Washington, Seattle 5.

LEE, H. R., "Comparative Shear Tests for the Analysis of the Stability of Selected Aggregates." M.S. in Civil Engineering, 1954.

This research was basically a small link in the cooperative research program of the Triaxial Institute's current program for analysis and development of a triaxial type of subgrade evaluation device. The program as it affected this research was the testing of three aggregates, two fine-grained subgrades and one coarse-grained base material, by a fixed procedure as provided by the Triaxial Institute, using the Hveem Stabilometer and related equipment. The test results were forwarded to the Triaxial Institute for evaluation with that of cooperating laboratories with respect to the reproductibility of test data.

The second portion of the research involved the testing of the two fine-grained soils by appropriate fundamental shear tests to determine their strength characteristics in terms of ordinary engineering units, angle of internal friction, and cohesion.

The tests used were as follows: undrained triaxial shear corrected for peak combined strength; undrained triaxial shear corrected for pore water pressure for intergranular peak strength; consolidated-quick direct shear for peak intergranular strength. The soils were tested at the same moisture content and degree of compaction used in the stabilometer study as a basis for comparison.

The results of the test program indicated that the Stabilometer, when used with the Triaxial Institute's procedure, gave conservative strength values to the soils tested.

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A cost criterion is defined for agricultural aircraft. The criterion is the product of costs per flight-hour times the utilization time, U, defined as the time to

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WASHINGTON COAL GASIFICATION STUDIES

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A Protean Haul from the *Journal of Engineering Education*

(Continued from page 1)

The extended four year program is based on the assumption that the last high school year may be taught at a university. In most cases the senior high school year cannot be satisfactorily modified to fit the special requirements of a revised engineering curriculum, at least not at the present time.

Furthermore, the plan presupposes that only those high school seniors who show a definite aptitude for science studies will be eligible for this program. . . . It relieves the standard four year engineering curriculum from certain basic science courses. . . .

It must be kept in mind, however, that many high school seniors have not matured enough to develop special aptitudes. Consequently, this choice of a science study at such an early stage must be optional and revocable.[6]

3. To streamline the humanistic-social program

Because time is so limited in the engineering curriculum, an attempt has been made in the teaching of the humanities and social studies in at least one engineering school to achieve some of the advantages which come from the compacting in the accumulative areas. The discussion method is used almost exclusively but great care is taken in the selection of the subjects for discussion and they are brought as far as possible into an orderly array within a four-year integrated program. This procedure gains ready acceptance among students used to the rigor and logic of engineering courses, and engineering schools have an unusually good opportunity of making a real contribution to teaching effectiveness in this area.[7]

4. To correlate the technological and humanistic-social courses

In point of time at my school, the basic courses in the physical sciences occupy about one and one-half years of the four-year program; the technological courses—about one and one-half years; and the basic courses in the social sciences and the other courses in this area—about one year . . . but success in the achievement of the main aims is found much more in how these courses are taught than in the particular curricular areas that have been covered. . . . The forces of education are not divided. Each curricular area is designed for training in fundamentals, for establishment and use of clear methods of analysis, for extension of knowledge and skills to other fields and for learning from experience. Moreover, the functions of the various curricular areas can be made complementary.[8]

5. To entrust the humanistic-social program to the engineering faculty, assuming that they ought to be able to transmit a "liberal education" in the course of their technical teaching.

Has anyone considered how the normal subject matter of engineering can lead to the civilizations of the Nile and of the Tigris and Euphrates. . . . Surely engineering drawing is not unrelated to ethics or logic, or to economics, or to the graphic and plastic arts, or to the temples which have housed the great religions of mankind. . . . Mathematics is an international language. It can be taught as an intellectual exercise, completely divorced from all social significance or reality. Or it may lead to the land measurements of the Egyptians, the construction of the Pyramids, or the dimensions of the solar system. . . . Or chemistry may be taught so that every teacher of chemistry is also a teacher of English speech and composition. . . He should possess a mastery of the fundamentals of the language and should possess and be able to induce in others a sense of style. . . . What we need . . . are teachers of professional and specialized subjects who see their subject matter in relation to the field of modern learning and modern civilization. In an institution possessing such teachers and likewise possessing an imaginative and intelligent student body, liberal education is bound to occur, whether the subject is contracts or classics, physics or politics, anatomy or art, soils or sociology, history or hydraulics.[9]

Two questions, however, would seem to confront the administrator who undertakes to develop this ideal institution: (1) where is he going to find such teachers today, in sufficient numbers, and (2) *who is going to train such teachers for tomorrow?*

A number of institutions have enlarged the jug by extending their undergraduate course to five years, along comparatively conventional lines, with an increase (though seldom proportional) of requirements in the humanistic-social fields. Moreover, combination programs of several types have recently been announced.

Cooperative programs enabling a student to obtain degrees in both liberal arts and engineering have been arranged by Stanford, Knox College, and the College of Idaho. Selected students at Knox and Idaho will take a three-year liberal arts course at their college, followed by two years of specialized training at the Stanford School of Engineering. Upon successful completion of the five-year course, the students will be awarded a bachelor of arts degree by their college and a bachelor of science degree by Stanford.[10]

A joint five-year liberal arts-engineering curriculum for students at the University Heights center of New York University . . . enables students to obtain the degrees of bachelor of arts and bachelor of engineering in a particular branch of engineering. Students declare their intention of pursuing the combined curriculum after the freshman year. The first-year curriculum is a normal liberal arts program. Each successive year introduces a greater proportion of engineering courses. . . . Degrees are awarded only after the fifth year, at which time the student has completed a major in engineering and two minors in liberal arts areas.[11]

A joint program in engineering and liberal arts between New York University and Rollins College, Winter Park, Florida, was announced. . . . Under the arrangement, Rollins College students may, after three years, transfer to the NYU College of Engineering as juniors. On completion of the combined five-year program, they will receive the degree of bachelor of engineering in a particular branch of engineering from NYU. Meanwhile Rollins will award the bachelor of science degree after the fourth year.[12]

The California Institute of Technology is inaugurating a "3-2 plan" for the admission of men from certain selected liberal arts colleges as juniors at Caltech. Colleges with which arrangements for participation in the plan have been completed include Occidental College, Los Angeles; Pomona College, Claremont; and Whitman College, Walla

Walla, Wash. Under the plan, a student may enroll in a cooperating college for an agreed-upon program for three years. On recommendation of the college he will then be admitted to Caltech as a junior. When he satisfactorily completes two more years of work at Caltech—for a total of five years of study—he will receive simultaneously the bachelor of arts degree from the college and the bachelor of science degree from Caltech.[13]

Most enlightening would be a forecast of how far the products of such plans ten years from now will measure up to the criteria of "complete competence in engineering" as set forth in the University of Nebraska's "Suggested Statement of Policy for Engineering Education."[14]

a. An understanding of mathematics and the physical sciences; a knowledge of the characteristics of materials; and familiarity with engineering methods;—resulting in ability to analyze, design, construct, operate or manage engineering works or projects.

b. An understanding of economics and finance;—resulting in ability to organize the efforts of individuals and groups in an effective prosecution of engineering works.

c. An understanding of the fundamentals of human conduct and the principles of management;—resulting in ability to organize the efforts of individuals and groups in an effective prosecution of engineering works.

d. A facility in forms of expression;—resulting in ability to discourse in written and oral form in the language of the arts as well as in the symbolic language of science.

e. An understanding of the evolution of the social organizations in which we live;—resulting in ability to appraise the influence of science and engineering on their development.

f. Familiarity with the great documents of arts, morals and religion;—resulting in an appreciation of the dignity and worth of human personality, the principle of social justice, and the principle of sharing for professional and social gain.

g. An appreciation of the obligations of citizenship;—resulting in a readiness to give intelligent service in the improvement of home, church, school and state.

h. An enthusiasm for learning;—resulting in a burning desire to continue the study of engineering and to search for the values in other fields of thought.

The engineering educator, however, is aware not only of the limitations of time and space—to an engineer, a full jug is *full*—but of the immediate urgency of the need.

It is obvious that within the time available, we cannot hope to make of student engineers, scholars in any of the areas of the humanities. In this sense the engineers remain laymen. Yet, they are expected to become men of action, busy with problem-solving and decision making, at home and over-seas, in broad areas of human affairs. There are more than three hundred thousand engineers in this country alone. Their recommendations and decisions will affect the lives of many. True scholars in the various specialized areas of the humanities are fewer in number, and most of these remain at the colleges. It is upon laymen such as the engineers that we must rely for many changes and, hopefully, we say for improvements. There exists a responsibility to develop these men not particularly in the direction of scholarly attainment in specialized fields, but for problem-solving based upon a working knowledge in many areas.[15]

Nor dare we forget that inserting the humanities into the curriculum is only the first step. Academic divisions other than those of engineering, and professors of courses in such divisions, have also been the targets for criticism!

Too often, the universities have become a repository for the humanities rather than their interpreter in the broad stream of American culture. . . . Too many professors are content to botanize upon the grave of the humanities.[16]

Perhaps teaching of the humanities, when viewed through the unjaded engineering eye, may be revitalized for other eyes, as well. But that is another story!

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drop one payload. Once the payload is specified, this criterion is dependent only on the airplane and not on the operation. The effect of the various design considerations on this criterion is discussed. The weights are shown to define the effects of items such as fuel load, wing area, and aspect ratio. Performance is shown to be limited by practical considerations of pilot reaction time and structural load factor. Typical performance is plotted to show the effect of the variables. The cost factors affected by wing loading and aspect ratio are defined. An investigation is conducted into the airfoil sections possessing high maximum lift coefficients.

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